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The Role of Pesticides in Fruit Fly Management, Balancing Efficacy and Environmental Concerns

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ABSTRACT

Fruit fly infestation is a major worldwide threat to food security by impacting fruit and vegetable production, especially in tropical and subtropical areas, tremendously. The pest infest more than 400 crop species by ovipositing within fruits and causing severe economic and aesthetic losses between 40–80%, depending on the species, season, and locality. Nations have placed strict quarantine requirements to avoid the danger of invasive species, with the European Union having been reported to reject entire shipments over a single infested fruit. Various control methods have been applied, but conventional pesticides like organophosphates, pyrethroids, and neonicotinoids, while at first effective, are currently encountering setbacks through resistance development and negative environmental effects. Therefore, Integrated Pest Management (IPM) has grown up as a more environmentally friendly approach that integrates chemical, biological, and cultural controls. Spinosad, abamectin, and microbial biopesticides are potential tools that can be used to minimize infestations while keeping damage to non-target organisms to a minimum. Emerging strategies such as RNA interference (RNAi) provide species-specific control with little ecological footprint, yet worry on non-target effects and regulatory environments abounds. Emerging challenges encompass climate change-induced pest outbreaks, gaps in resistance monitoring, and socio-economic inequalities to access safer technologies. Overcoming these demands strong policy support, farmer training, fair access to innovations, and inter-institutional collaboration among academia, industry, and governments. Consumer purchasing of residue-free fruit and changing Maximum Residue Limit (MRL) policies are redefining pesticide application and trade flows. Generally, innovations in pest control strategies that are effective, ecologically sound, and socially just are essential to ensuring global food systems in light of new pressures and environmental uncertainties.

INTRODUCTION

The availability of food is being threatened by crop pests and diseases (Bebber, Holmes et al. 2014). Fruit fly infestations are one of the primary threats among many other issues. As their name suggests, fruit flies are actual flies that consume fruits. Fruit flies are beneficial pests that are members of the Tephritidae family, which has 481 genera and around 4000 species, and the order Diptera (Reddy, Devi et al. 2020). India is home to roughly 5% of these species (Ganie, Khan et al. 2013, Mariadoss 2020). These can be found anywhere on Earth where there is adequate life, from open savannah to rainforests. These insects are found all throughout the world, with the exception of Antarctica (Kabbashi 2014).

Many fruit fly varieties pose serious risks to global fruit and vegetable manufacture, resulting in both monetary and aesthetic losses. Fruit flies, including Halyomorpha halys (Brown Marmorated Stink Bug) and Drosophila suzukii (Spotted Wing Drosophila), are some of the most devastating nuisance insects that impact fruit harvests in Europe and around the world. Likewise many fruit-producing nations have implemented quarantine restrictions on the importation of goods from countries infested with specific fruit fly species, and/or demand that agricultural products undergo confinement treatment prior to their shipment being permitted, due to their vulnerability to invasive tephritid species.

Fruit flies puncture veggies to lay their eggs and develop larvae inside the fruit, causing serious harm to the produce all at once (Aluja 1994). Nearly 400 different fruits and vegetables, including some crucial ones like apple, guava, mango, citrus, peach, papaya, melon, passion fruit, and plum, are harmed by female fruit flies that lay their eggs within fruits. They can fly up to two km in pursuit of food, demonstrating their exceptional flying skills (Singh, Agrawal et al. 2020). According on their range, location, and season, these pests directly damage a variety of plants, resulting in losses ranging from 40 to 80% (Kibira, Affognon et al. 2015). The existence of these pest species and quarantine regulations in importing nations limit access to global markets (Lanzavecchia, Juri et al. 2014). Strict quarantine regulations have been implemented by the European Union (EU) for the importation of fresh goods. The entire mango shipment will be cancelled and destroyed if only one larva is found on the mango fruit at the entry point. The EU then imposes a ban on that specific exporting nation. Because of their destructive worldwide effects on horticultural enterprises and the fact that the problem is transboundary, fruit flies have become the most important insect pests in the sector (Enkerlin 2021). They result in an annual loss of 910 million US dollars in California, and an estimated 100 million Australian dollars in

Australia.In poor nations, the situation is worse; Egypt, for instance, spends millions of dollars to maintain control. Furthermore, FAO raises concerns by hosting conferences on the subject and requesting scientific collaboration on it (Ekesi 2010). Biological control has been the most often investigated control method (29%), followed by chemical control (20%), behavioural control, including SIT (18%), and quarantine treatments (17%). Various management techniques have been used to control these pests.

MANAGEMENT STRATEGIES

The majority of the broad spectrum, potent, and systemic-acting pesticides are being phased out of the market, making fruit fly management more difficult in many international locations (Böckmann, Köppler et al. 2014). Fruit flies lay their eggs within ripening fruit, maggots develop inside the fruit, and last-instar larvae cross for pupation in soil, making them difficult to control and resistant to insecticides (Heve, El-Borai et al. 2017). A few strategies are needed for effective control of fruit flies because it is impractical to use only one method. Each approach has unique benefits and drawbacks.For example, the male annihilation technique (MAT) are especially effective for certain species of Bactocera but not for others due to a lack of suitable baits. Likewise, the sterile insect method (SIT) demands the target pest to be raised in substantial quantities and the discharge sector to be geographically isolated (Suckling, Kean et al. 2016). To protect our crops from this pest, we must hence employ a variety of integrated control strategies.

Among the most widely used classes of chemicals for controlling crop-related insects, including fruit flies, are standard pesticides like organophosphates, pyrethroids, and neonicotinoids..

- In insects, organophosphates cause paralysis and death by blocking acetylcholinesterase, an enzyme necessary for nerve activity..
- By extending the opening of sodium channels in insect neurones, pyrethroids—synthetic analogues of natural pyrethrins—disturb the neurological system..
- Neonicotinoids are frequently used as foliar sprays or treatments for seeds because of their widespread impact on nicotinic acetylcholine receptors.

Even while these insecticides work well, overuse and recurrent use have caused many pest species to become resistant, which gradually reduces their effectiveness. Concern over their non-target consequences is also developing. These include detrimental effects on aquatic life, soil organisms, helpful insects (such as bees and natural predators), and even human health. Additionally, overuse can result in ecological imbalance and biodiversity loss, which compromises the long-term viability of pest management techniques.

BIO-PESTICIDES

Natural compounds from microorganisms and plants are known as biopesticides (Mazid, Kalita et al. 2011). It has been demonstrated that natural compounds derived from plants, such as azadirachtin from neem and Azadirachta indica, may effectively control about 12 fruit flies worldwide (Singh 2003, Silva, Bezerra-Silva et al. 2013). According to (Alvarenga, Brito et al. 2005), these products have also been employed with parasitoids. The effectiveness of three biopesticides—Spinosad, Abamectin, and Lecanicillium muscarium—against fruit fly attacks on bitter gourd (Momordica charantia L.) was assessed by (Rahman, Howlader et al. 2019). When compared to the control, all of the biopesticides, both separately and in combination, dramatically decreased the fly infestation at varying degrees. Spinosad used alone has a moderate level of effectiveness. The best method for achieving the maximum proportion of healthy fruits and the least amount of fruit infestation was to combine Spinosad with L. muscarium. Spinosad has been widely used as a bait to control fruit flies. Research has focused on foraging factors attractiveness and efficacy (Yee, Jack et al. 2007), and residual control and toxicity. The effects were assessed for oviposition, mortality, and emergence (Yee and Alston 2006, Yee 2011). The effectiveness of various biopesticides against fruit fly infestation on bottle gourds was also assessed by (Alam and Khan 2021). For the control of cucurbit fruit flies on a bottle gourd, they recommended Spinosad (Tracer 45 SC) out of all the treatments that were examined. The best biopesticide against fruitflies was suggested to be spinosad. Spinosad outperformed neem oil, which was followed by abamectin (Ambush 1.8 EC), allamanda leaf extract, and mahogany oil. Under field-caged conditions, abamectin's toxic properties have also been suggested as a substitute for diazinon in soil treatment against Bactrocera zonata, the peach fruit fly (PFF). According to these investigations, abamectin may be applied as a soil treatment to manage PFF pupae.

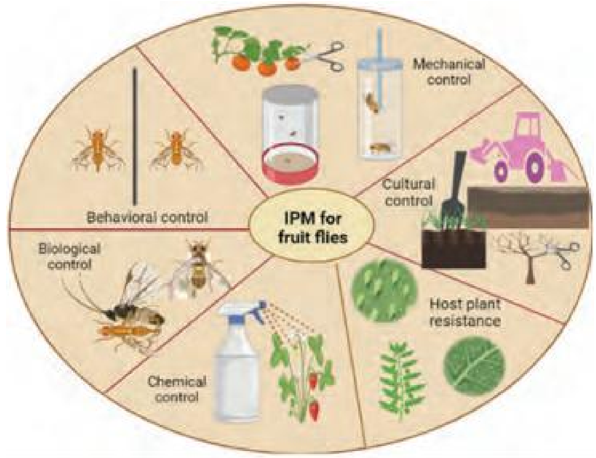

FIG 1: INTEGRATED PEST MANAGEMENT FOR FRUIT FLIES

USE OF PESTICIDES IN BALANCING EFFICACY

Because it protects crops and stabilizes economic returns, the use of pesticides against fruit flies—especially invasive species—is essential to modern agriculture. Due to their aggressive feeding habits and quick reproduction, these pests significantly reduce fruit and vegetable production worldwide. Because of their quick and quantifiable effectiveness in lowering insect populations, pesticides have historically been the primary line of defense. Their use has been crucial for crop output, enabling farmers to produce market-quality fruits free of defects or infestations, lowering post-harvest losses, and upholding trade standards. However, the extensive and careless use of synthetic pesticides has sparked serious concerns about sustainability due to the negative effects on the environment and human health. Therefore, striking a compromise between preserving pest management effectiveness and reducing adverse ecological and environmental effects is the key task (Harun-Ur-Rashid and Imran 2025).

Refining the use of pesticides to attain this balance has become the focus of scientific and regulatory attention in recent years. In what is known as Integrated Pest Management (IPM), this entails choosing suitable formulations (such as slow-release or low-toxicity), optimising delivery methods (such as targeted spraying, bait systems), and combining these with biological and cultural controls. For instance, fruit fly populations can be precisely targeted while limiting exposure to non-target organisms with attract-and-kill tactics that combine insecticides with semiochemicals like methyl eugenol. Similarly, when applied sparingly, systemic insecticides like neonicotinoids, despite their controversy, provide protection for the entire plant with little surface residue. Crucially, alternating pesticide classes and keeping an eye out for resistance contribute to maintaining their long-term effectiveness (Thier 2001). Resistance management is a crucial component of an environmentally responsible pesticide strategy since the development of insect resistance is a significant disadvantage of excessive pesticide use. Adjuvants are another component of contemporary formulations that improve efficacy and enable the use of lower quantities of the active ingredient, thus lessening the environmental impact.

Furthermore, sophisticated delivery methods including microencapsulation, controlled-release matrices, and bio-carriers like zeolite or chitosan might reduce health and environmental hazards. These carriers minimize off-target impacts on pollinators, aquatic systems, and soil microbiota by increasing pesticide stability, lowering volatilization, and enabling targeted release. Fruit crops, which are frequently eaten raw and are subject to strict Maximum Residue Limits (MRLs), are a prime example of this. Global regulatory organizations, such as the EPA, EFSA, and Codex Alimentarius, have started to enforce stricter regulations on pesticide residues, pushing manufacturers to switch to safer substitutes or more sophisticated usage guidelines. Because of their lower toxicity profiles and biodegradability, biopesticides—which are made from botanical extracts, microbial metabolites, or naturally occurring compounds—have drawn interest. For example, it has been demonstrated that essential oils from Monarda didyma decrease oviposition in D. suzukii while quickly decomposing in the environment.

Furthermore, RNA interference (RNAi) technologies offer species-specific gene silencing with minimal ecological spillover, making them a cutting-edge frontier in fruit fly control. The effects of using dsRNA to silence important metabolic genes in pests like H. halys are strong and specific to the target species (Hung and Slotkin 2021). RNA interference (RNAi) is an excellent example of ecologically compatible efficacy since, in contrast to conventional neurotoxic insecticides, it does not damage non-target organisms or persist in the food chain. Uptake efficiency and environmental safety are further improved by delivering RNAi constructs using natural carriers like chitosan. These advancements show a paradigm shift away from broad-spectrum pesticides and towards residue-free, biodegradable, and precisely tailored treatments.

Additionally, legislative support, regulation, and teaching are also necessary to strike a balance among environment safety and efficacy. To stop resistance and environmental damage, farmers need to be trained in safe handling, dose, application schedules, and rotation techniques. By supporting IPM frameworks that combine chemical, biological, and mechanical techniques adapted to regional agro-ecological conditions, governments and agricultural extension agencies play a critical role. To establish accountability throughout the supply chain, laws that encourage pesticide audits, reward low-impact alternatives, and punish abuse are crucial. Campaigns to raise public awareness also strengthen customer demand for product that is farmed responsibly, which incentives the market for pesticide reform.

Lastly, acknowledging the socioeconomic reality of smallholder farmers is another way to strike a balance between environmental concerns and efficacy. To guarantee broad adoption, safer pesticide technologies, diagnostic instruments, and pest surveillance systems must be accessible and reasonably priced. In order to provide solutions that are affordable, scalable, and culturally acceptable across various farming communities, research institutes must place equal emphasis on innovation and accessibility. To bridge the gap between laboratory efficacy and field practicality, policymakers, industry, and academia must work together.

FUTURE CONCERNS

Notwithstanding these developments, there are still a number of urgent issues with the use of pesticides in fruit fly control. Pesticide resistance is one of the main problems. If not handled carefully, even biopesticides and more recent technologies may become vulnerable when pests become accustomed to widely used insecticides. Although proactive rotation tactics and resistance monitoring will be crucial, many areas lack the surveillance infrastructure necessary to track the progress of resistance in real time. A further degree of intricacy is introduced by climate change. Fruit fly species may spread their range and rate of reproduction due to warmer temperatures, which could increase their economic danger by forcing them into previously unaffected areas. Management tactics may become even more complex as a result of these changes, which may also affect pest behaviour and pesticide degradation rates. The possibility of unforeseen ecological effects from developing technologies is another worry for the future. RNA interference (RNAi) has a lot of potential, but there are still issues with gene silence in non-target species, off-site dsRNA movement, and possible impacts on helpful insects like pollinators or parasitoid wasps. In order to systematically assess these risks, regulatory frameworks are still developing. To be sure their degradation profiles are in fact benign, the environmental persistence of innovative formulations—even those promoted as "green"—must be investigated in real-world settings.

Risks to human health are still a concern, particularly in areas where workers and farmers do not have access to PPE or pesticide safety training. To promote safer pesticide practices in both large-scale and smallholder farming systems, educational initiatives and participatory extension systems are required. From a policy perspective, evolving laws, especially those pertaining to Maximum Residue Limits (MRLs) and chemical bans, will have a significant impact on future pesticide use. Stricter export regulations may spur innovation and compel manufacturers to switch to safer, lower-residue goods. The issue of fairness and access is also brought up by this, since farmers with little resources could find it difficult to adopt or purchase modern technologies in the absence of government funding or subsidies.

Furthermore, market dynamics and pesticide restrictions will be impacted by consumer awareness and demand for organic or residue-free products. To satisfy changing consumer demands, producers will need to make investments in traceability tools, non-chemical substitutes, and residue control methods. Therefore, the creation of reasonably priced and efficient pest control solutions that may be universally embraced across socioeconomic situations must be a top priority for research institutions. In this climate, cooperation between academia, business, and politicians will be essential to promoting inventions that are sound from a scientific standpoint, profitable, and ecologically conscious. To avoid adoption delays brought on by regulatory uncertainty, it will also be crucial to standardise environmental risk assessments for RNAi technologies and biopesticides.Designing resilient, adaptable, and multipurpose pest management strategies that concurrently address yield protection, environmental integrity, and socioeconomic fairness must be the long-term objective.

CONCLUSION

Fruit fly control is a complex issue that affects environmental sustainability, agricultural production, and the integrity of international trade. Although synthetic pesticides have historically been successful in controlling fruit fly infestations and guaranteeing crop security, their negative effects on the environment and human health have made a move towards more integrated and balanced methods necessary. Precision, safety, and sustainability are becoming more and more important in the evolution of pesticide techniques. New technologies like RNA interference and biopesticides provide focused control with little ecological impact. The most promising strategy to strike a compromise between effectiveness and long-term ecological and public health issues is through Integrated Pest Management (IPM) frameworks that integrate chemical, biological, and cultural tactics.But there are also major obstacles in the way of pesticide use in the future. The sustainability of current methods is seriously threatened by pesticide resistance, climate change, and socioeconomic disparities in access to technology. Furthermore, consumer-driven demands for residue-free product and regulatory ambiguity around developing biotechnologies necessitate responsive policies and coordinated stakeholder involvement. Investments in scientific research, surveillance infrastructure, farmer education, and fair policy assistance will be essential in the future. In the end, managing fruit flies successfully will require striking a balance between innovation and accountability, maintaining pest control efficacy while protecting the environment and fostering agricultural resilience in both developed and developing nations.

REFERENCES

Alam, R. and M. R. Khan (2021). "Efficacy of some biopesticides for the management of cucurbit fruit fly (Bactrocera cucurbitae Coquillett) infesting bottle gourd (Lagenaria siceraria) in Barind tract of Bangladesh." Journal of Entomology and Zoology Studies **9**(6): 203-207.

Aluja, M. (1994). "Bionomics and management of Anastrepha." Annual Review of Entomology **39**: 78-155.

Alvarenga, C., et al. (2005). "Introduction and recovering of the exotic parasitold Diachasmimorpha longicaudata (Ashmead)(Hymenoptera: Braconidae) in commercial guava orchards in the north of the State of Minas Gerais, Brazil." Neotropical Entomology **34**(1): 133-136.

Bebber, D. P., et al. (2014). "Economic and physical determinants of the global distributions of crop pests and pathogens." New Phytologist **202**(3): 901-910.

Böckmann, E., et al. (2014). "Bait spray for control of European cherry fruit fly: an appraisal based on semi-field and field studies." Pest Management Science **70**(3): 502-509.

Ekesi, S. (2010). "Combating fruit flies in Eastern and Southern Africa (COFESA): Elements of a strategy and action plan for a regional cooperation program." World bank.

Enkerlin, W. (2021). Impact of fruit fly control programmes using the sterile insect technique. Sterile insect technique, CRC Press: 979-1006.

Ganie, S., et al. (2013). "Identification and taxonomical studies of fruit flies on cucurbits in Kashmir valley." Bioscan **8**(1): 263-269.

Harun-Ur-Rashid, M. and A. B. Imran (2025). "Biomimetic and Synthetic Advances in Natural Pesticides: Balancing Efficiency and Environmental Safety." Journal of Chemistry **2025**(1): 1510186.

Heve, W. K., et al. (2017). "Biological control potential of entomopathogenic nematodes for management of Caribbean fruit fly, Anastrepha suspensa Loew (Tephritidae)." Pest Management Science **73**(6): 1220-1228.

Hung, Y.-H. and R. K. Slotkin (2021). "The initiation of RNA interference (RNAi) in plants." Current Opinion in Plant Biology **61**: 102014.

Kabbashi, E. B. M. (2014). "Fruit insect pests of guava (Psidium guajava L.) and mango (Mangifera indica L.) and their management in Sudan: A historic review." US open food science and technology journal **1**(3): 1-11.

Kibira, M., et al. (2015). "Economic evaluation of integrated management of fruit fly in mango production in Embu County, Kenya." African Journal of Agricultural and Resource Economics **10**(4): 343-353.

Lanzavecchia, S. B., et al. (2014). "Microsatellite markers from the'South American fruit fly'Anastrepha fraterculus: a valuable tool for population genetic analysis and SIT applications." BMC Genetics **15**: 1-8.

Mariadoss, A. (2020). "Species diversity of fruit flies in different varieties of mango in Ranga Reddy District of Telangana State, India." Journal of Entomology and Zoological Studies **8**(4): 184-187.

Mazid, S., et al. (2011). "A review on the use of biopesticides in insect pest management." Int J Sci Adv Technol **1**(7): 169-178.

Rahman, M. M., et al. (2019). "Efficacy of three biopesticides against cucurbit fruit fly, Bactrocera cucurbitae Coquillett (Diptera: Tephritidae) and yield of bitter gourd: Efficacy of three biopesticides against cucurbit fruit fly." Journal of the Bangladesh Agricultural University **17**(4): 483-489.

Reddy, K. V., et al. (2020). "Management strategies for fruit flies in fruitcrops—A Review." JETIR **7**(12): 1472-1480.

Silva, M., et al. (2013). "Neem derivatives are not effective as toxic bait for tephritid fruit flies." Journal of Economic Entomology **106**(4): 1772-1779.

Singh, S. (2003). "Effects of aqueous extract of neem seed kernel and azadirachtin on the fecundity, fertility and post-embryonic development of the melonfly, Bactrocera cucurbitae and the oriental fruit fly, Bactrocera dorsalis (Diptera: Tephritidae)." Journal of Applied Entomology **127**(9-10): 540-547.

Singh, S., et al. (2020). "Management of fruit flies in mango, guava and vegetables by using basil plants (Ocimum sanctum L.) as attractant." Journal of Entomology and Zoology Studies **8**(1): 311-314.

Suckling, D. M., et al. (2016). "Eradication of tephritid fruit fly pest populations: outcomes and prospects." Pest Management Science **72**(3): 456-465.

Thier, A. (2001). "Balancing the risks: vector control and pesticide use in response to emerging illness." Journal of Urban Health **78**: 372-381.

Yee, W. L. (2011). "Mortality and oviposition of western cherry fruit fly (Diptera: Tephritidae) exposed to different insecticide baits for varying periods in the presence and absence of food." Journal of Economic Entomology **104**(1): 194-204.

Yee, W. L. and D. G. Alston (2006). "Effects of spinosad, spinosad bait, and chloronicotinyl insecticides on mortality and control of adult and larval western cherry fruit fly (Diptera: Tephritidae)." Journal of Economic Entomology **99**(5): 1722-1732.

Yee, W. L., et al. (2007). "Mortality of Rhagoletis pomonella (Diptera: Tephritidae) exposed to field-aged spinetoram, GF-120, and azinphos-methyl in Washington State." Florida Entomologist **90**(2): 335-342.